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1998 SUMMER RESEARCH PROGRAM FOR HIGH SCHOOL JUNIORS

AT THE

UNIVERSITY OF ROCHESTER'S

LABORATORY FOR LASER ENERGETICS

STUDENT RESEARCH REPORTS

PROJECT COORDINATOR

Dr. R. Stephen Craxton

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Laboratory Report 300

Laboratory for Laser Energetics
University of Rochester

DISCLAIMER

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During the summer of 1998, 11 students from Rochester-area high schools participated in the Laboratory for Laser Energetics' Summer High School Research Program. The goal of this program is to excite a group of high school students about careers in the areas of science and technology by exposing them to research in a state-of-the-art environment. Too often, students are exposed to "research" only through classroom laboratories that have prescribed procedures and predictable results. In LLE's summer program, the students experience all of the trials, tribulations, and rewards of scientific research. By participating in research in a real environment, the students often become more excited about careers in science and technology. In addition, LLE gains from the contributions of the many highly talented students who are attracted to the program.

The students spent most of their time working on their individual research projects with members of LLE's technical staff. The projects were related to current research activities at LLE and covered a broad range of areas of interest including optics, spectroscopy, chemistry, diagnostic development, and materials science. The students, their high schools, their LLE supervisors and their project titles are listed in the table. Their written reports are collected in this volume.

The students attended weekly seminars on technical topics associated with LLE's research. Topics this year included lasers, fusion, holography, nonlinear optics, global warming, and scientific ethics. The students also received safety training, learned how to give scientific presentations, and were introduced to LLE's resources, especially the computational facilities.

The program culminated with the High School Student Summer Research Symposium on 26 August at which the students presented the results of their research to an audience that included parents, teachers, and members of LLE. Each student spoke for approximately ten minutes and answered questions. At the symposium an Inspirational Science Teacher award was presented to Mr. David Crane, a chemistry teacher at Greece Arcadia High School. This annual award honors a teacher, nominated by alumni of the LLE program, who has inspired outstanding students in the areas of science, mathematics, and technology.

High School Students and Their Projects (1998)			
Student	**High School**	**Supervisor**	**Project**
Steven Corsello	Pittsford Mendon	K. Marshall	Computer-Aided Design and Modeling of Nickel Dithiolene Near-Infrared Dyes
Peter Grossman	Wilson Magnet	R. S. Craxton	Group Velocity Effects in Broadband Frequency Conversion on OMEGA
Joshua Hubregsen	Pittsford Sutherland	S. Jacobs	A Study of Material Removal During Magnetorheological Finishing (MRF)
Nieraj Jain	Pittsford Sutherland	M. Guardelben	Analyzing Algorithms for Nonlinear and Spatially Nonuniform Phase Shifts in the Liquid Crystal Point Diffraction Interferometer
Leslie Lai	Pittsford Mendon	M. Wittman	The Use of Design-of-Experiments Methodology to Optimize Polymer Capsule Fabrication
Irene Lippa	Byron-Bergen	K. Marshall	Synthesis and Analysis of Nickel Dithiolene Dyes in a Nematic Liquid Crystal Host
Phillip Ostromogolsky	Brighton	F. Marshall	Investigation of the X-Ray Diffraction Properties of a Synthetic Multilayer
Michael Schubmehl	The Harley School	R. Epstein	An Analysis of the Uncertainty in Temperature and Density Estimates from Fitting Model Spectra to Data
Joshua Silbermann	Penfield	P. Jannimagi	Automated CCD Camera Characterization
Abigail Stern	The Harley School	J. Knauer	Design and Testing of a Compact X-Ray Diode
Amy Turner	Churchville-Chili	R. S. Craxton	Ray Tracing Through the Liquid Crystal Point Diffraction Interferometer

A total of 91 high school students have participated in the program since it began in 1989. The students this year were selected from approximately 60 applicants. Each applicant submitted an essay describing their interests in science, a copy of their transcript, and a letter of recommendation from a science or math teacher.

LLE plans to continue this program in future years. The program is strictly for students from Rochester-area high schools who have just completed their junior year. Applications are generally mailed out in February with an application deadline near the end of March. For more information about the program or an application form, please contact Dr. R. Stephen Craxton at LLE.

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AUTOMATED CCD CAMERA CHARACTERIZATION

by

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AUTOMATED CCD CAMERA CHARACTERIZATION

Josh Silbermann
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LABORATORY FOR LASER ENERGETICS
University of Rochester

Summer High School Research Program
1998

I. INTRODUCTION

Today's world offers many choices to researchers who need cameras for their work. The main two options in use are film based cameras and CCD (charge-coupled device) cameras. There are quite a few advantages to using CCD cameras. CCD cameras allow for much faster acquisition of data than do film based cameras. After the end of the exposure, an image is displayed within tenths of a second to a few seconds, depending on the CCD. Once the data is obtained it can be sent quickly to a variety of locations for analysis. Using a computer to analyze the digital picture makes calculations easy . CCD cameras are also much more sensitive (by approximately 30 times) and provide a better signal-to-noise ratio. The spatial resolution of film is in fact superior to a CCD because the resolution of a CCD is determined by the size of the pixels on the array. Despite this, CCD camera do have adequate spatial resolution for most scientific work.

A CCD is composed of a 2-D array of potential wells. These potential wells are used to collect and measure incoming light. The wells, when exposed to incident photons, create electron-hole pairs which are then stored. A polysilicon gate with a positive charge creates a depleted space where the electrons are kept. Crystalline silicon is used because of its covalently bonded structure from which electron-hole pairs are created easily. Full frame CCD arrays are divided into a parallel register and a serial register. The parallel register is the region where the light is collected. The serial register is masked so light cannot enter it. This area is actually a 1-D CCD involved in the charge transfer process when the array is readout.

Before taking an exposure the CCD array will be cleared for a variable number of cycles. The shutter will then open allowing light to strike the surface of the CCD. After the integration period is finished, the shutter will close. In order to get the data from the potential wells into the computer for analysis, the charge packets need to be individually fed through an amplifier and an analog-to-digital converter. To get the packets out of the array, the parallel register is shifted toward the serial register one row at a time. The serial register is then shifted a pixel at a time toward the output. Once the serial register has been emptied. the parallel register shifts over another row of pixels, once again filling the serial register. In order to move charges across the parallel register, a programed series of potentials is applied to the wells to allow the charge packets to "spill" over to the adjacent well. This method of transferring charges is how the name charged-coupled device was developed. The efficiency of this process in scientific grade cameras is near perfect (0.99999). The array will continue to be shifted until all the pixels have been readout. The computer can then display the image and quickly calculate a variety of important information including mean signal level, standard deviation, and maximum/minimum pixel values.

The OMEGA system uses CCD cameras for a broad range of applications. Over 100 video rate CCD cameras are used for such purposes as targeting, aligning, and monitoring areas such as the target chamber, laser bay, and viewing gallery. There are approximately 14 scientific grade CCD cameras on the system which are used to obtain precise photometric results from the laser beam as well as target diagnostics. It is very important that these scientific grade CCDs are properly characterized so that the results received from them can be evaluated appropriately.

Currently characterization is a tedious process done by hand. The operator must manually operate the camera and light source simultaneously. Because more exposures means more accurate information on the camera, the characterization tests can become very lengthy affairs. Sometimes it takes an entire day to complete just a single plot. Characterization requires the testing of many aspects of the camera's operation. Such aspects include the following:

- **variance vs. mean signal level:** this should be proportional due to Poisson statistics of the incident photon flux.
- **linearity:** the ability of the CCD to produce signals proportional to the light it received.
- **signal-to-noise ratio:** the relative magnitude of the signal vs. the uncertainty in that signal.
- **dark current:** the amount of noise due to thermal generation of electrons (cooling lowers this noise contribution significantly).

These tests, as well as many others, must by conducted in order to properly understand a CCD camera. The goal of this project was to construct an apparatus that could characterize a camera automatically.

II. AUTOMATING THE PROCESS

The basic components required for building an automated characterization system are: a pulsed light source that is spatially uniform, a CCD camera coupled to the light source, and computer controls for integrating the light source and the camera.

The light source being used is an LED panel housed in the back of a four mirror kaleidoscope. When the light reaches the end of the kaleidoscope the field is fairly uniform. In order to control the light source with very high precision, a reliable timing device was required. Using software delays as the timing mechanism would not have been reliable because the computer delegates which operations receive priority and which do not. Other system tasks could cause software delays to fluctuate because the computer will attend to them first. The timing for the light source was achieved using a data acquisition daughter-board. The data acquisition board has a 1MHz clock built in as well as three counters, four digital-out ports and three digital-in ports. The board produces Transistor Transistor Logic signals (TTL) making control easy because there are only two states: TTL high (approximately 5 volts) and TTL low (zero volts). Control over the data acquisition board is done through Visual C++.

In order to control the light source, the 1MHz clock is used to send pulses to the Counter 0 input. There was a problem initially getting the clock pulses into the counter so a jumper was installed on the daughter-board linking the 1MHz output with the Counter 0 input directly. The operation of the counter is fairly simple. Counter 0 is initially set to a desired configuration and then assigned a loadvalue from which it will decrement each time it receives a pulse from the clock. The Counter 0 output is normally set high. When the counter begins to decrement, the output will go low and remain low until the counter reaches 0 at which point the output will be pulled high. In order to gain even more precise control over the counter, a configuration called hardware retriggerable one-shot was used. In this configuration, the counter will not begin to decrement until it receives a trigger. Upon receiving trigger, the counter output will go low on the next clock pulse where it will remain until the counter equals zero. Using the one-shot configuration allows for precise control because an initial count of X will produce a one-shot pulse of X clock cycles. Triggering Counter 0 required the use of Gate 0, which is hard-wired directly into the counter. Gate 0 normally sits high. Pulling it low acts as the trigger, initiating the counter. Controlling Gate 0 was accomplished by wiring it to one of the digital outputs. Since the digital outputs can easily be switched to TTL high or TTL low, control over the gate was done through this digital output. A diagram of the data acquisition board is shown in figure 1.

Using Microsoft Visual C++, a function was written so that controlling the light source could be done simply by entering a few parameters. The function (known as pulser) provided the trigger for the counter as well as the appropriate delays to prevent accidental retriggering. The pulser function accepted three parameters from the user. One parameter controlled the delays around the trigger, another controlled the amount of times to trigger the counter (usually 1 per call), and the last contained the loadvalue for the counter. The data acquisition board sends its signals through a DB37 computer cable, where it was easy to test for TTL signals using a multimeter. When the function was run. Counter 0 output was going low for the desired amount of time then returning high. The next step was to change the low going counter output into a signal that could drive the LED array.

In order to drive the LED array, the output from the data acquisition board needed to be inverted as well as amplified. A device was constructed the accomplish this task (see figure 2). The DB37 cable brought the Counter 0 output signals into a TSC428 chip, designed to convert TTL signals into a high voltage/high current output. The TSC428 has two outputs, one of which is inverted and one of which is not. The non-inverted output runs to a pulse indicator light whose function is to give the operator a visual cue as to when the LED array is pulsing. Before reaching the indicator light, the TTL signal goes through an NE555 chip. This chip inverts the input and adjusts the incoming pulse duration to make it more visible to the eye. The inverted output from the TSC428 runs through an IRFZ22 hexfet to a BNC output. The power for the circuit is controlled by a simple voltage regulator circuit that uses a LM317 voltage regulator. The output voltage to the LED array is currently set to 15vdc. The LED array was hooked to the BNC output from the pulse amplifier, and the pulser function was run. The array responded appropriately to the parameters in the function. The electrical waveform powering the LED array was checked with an oscilloscope. After adding some additional capacitance and filtering to the circuit we were able to produce square signals with 100 ms risetimes and negligible droop over 100 ms durations. There may be a need in the future to add additional filtering and/or current limiting to the circuit. The LEDs are being pushed very hard by the amplifier and small changes in the loadvalue are producing to much charge in the CCD array. This prevents very precise analysis between points.

Control of the camera was done through a program known as Camtest. Camtest, written by Photometrics, is the most basic program for acquiring a CCD exposure. Camtest is written in C++ which is part of the reason the decision was made to complete the pulser function in Visual C++. Visual C++ also offers the ability to create a very neat graphical user interface (GUI). By analyzing the Camtest code, specifically the code used to control the shutter and take the exposure, an appropriate location for the puler function was determined. The pulser function was inserted into Camtest between the the opening and closing sequences of the shutter. Software delays are used to space enough time between the shutter opening and the pulsing of the light source. Running this enabled an image to be taken at a certain brightness level under computer control.

Camtest needed to be modified further to fit the desired testing requirements. Camtest could only hold a single image at a time, which is not sufficient for performing a characterization on a CCD camera. As we began to actually design the characterization system, we focused on the variance vs. mean signal level plot. This is the most fundamental test performed on a CCD in which one can determine a great deal about a CCD. A variance vs. mean signal level plot requires three frames at a time to calculate a single data point on the plot. Two of these exposures need to be for equal integration periods at equal brightness levels. The third must be for the same integration period as the previous two except for a brightness level of zero so that the background can be measured. In order to accomplish this, space was allocated for three frames at a time. A loop was created that would take three exposures, two for the same time and brightness level, and one dark frame. After each exposure the computer copies the information from Camtest's single image "container" into one of the three allocated arrays. The copying procedure is done inside a loop whose parameters can be changed in order to study specific regions of interest. The variability of the sub-arrays is important because sometimes it is necessary to focus on areas other than an entire CCD array. A situation where this would be encountered is when the CCD chip is seated toward the back of the camera housing such that the corners of the chip are blacked out. Part of the loop that takes the three exposure set is an array of loadvalues used for the counter. The loop control variable is set in the code to however many loadvalues exist in the array. Each three exposure set will correspond to a single loadvalue, and after the third exposure is completed the next set will commence with the following value in the array as the new loadvalue. To signal an end to the program, a -1 flag was used as the sentinel value. One problem that we discovered was that sending a zero in as a loadvalue caused that LEDs to stay on continuously. The best explanation for this is that the counter begins to decrement from zero, thus running infinitely. To get around this, a simple statement was placed in the pulser function that exits the function without pulsing the light source if a zero is input as the loadvalue.

Once the three images at a given brightness level have been exposed, calculations need to be made on those images to arrive at a set of coordinates for the plot. The computer will subtract the two non-dark frames from each other, calculate the variance on that frame and than divide by two (the variance of the two frames add), saving that value. Next the computer will subtract the dark frame from one of the other two images, calculate the mean signal level and save that result. Those two pieces of data which make up a variance vs. mean plot, as well as various other information is output to a file as the computer goes through a set of exposures. When an exposure set is complete, information can be retrieved from the output file and the variance and mean coordinates can be placed in a plotting program which can build a very helpful graph used to evaluate the CCD cameras. A least squares regression line can be generated with the collected coordinates. The inverse of the slope of the line is the system gain in electrons per ADU. The y-intercept is the read noise of the system.

III. Results & Future Development

Completing a variance vs. mean signal plot by hand can take upwards of an entire day and is susceptible to human error. The automated characterization allows the operator to walk away from the apparatus during data collecting for hands free operation. The automated system can take collect **more** data for a variance vs. mean signal plot in fifteen minutes than a person could accomplish in a whole day. The variance vs. mean signal plot shown in figure 3 required about 300 exposures to create and took approximately 25 minutes to collect. By examining the plot, which shows the camera at two different gain settings, we can obtain the read noise and system gains. Also, by examing where the points fall around the line, we can gather what is happening with the CCD. At gain 4, the points fall off the line towards the end as they begin to reach full well capacity. At gain 1, the points are most probably falling off because of analog-to-digital saturation. Figure four shows another typical plot, pulse duration versus CCD signal. The droop is not desired and may be fixed with electronic manipulations.

The system is very expandable and will be further developed in order to characterized all CCD cameras here at LLE. The plans for the system are to begin adding all characterization tests to the program. Then an operator could run any test desired or run an entire characterization program to do a full analysis on the camera. A full analysis might take a morning as opposed to a hand done characterization which takes around a week to complete. Because the program is in Visual C++, creating a nice user interface with characterization tests on a pull down menu would be very simple to accomplish. The program will also need to have a complex series of error check incorporated into it so that all errors in the characterization process can be detected. Error checks could include sensing a cosmic ray hit, detecting that the two non-dark frames in a variance/mean set are not similar enough (a requirement), or sensing light source problems. Each might result in the retaking of a data point. A threshold could be set so that if the error persists the system would shut down and give an appropriate error message. Also, a good mechanical apparatus will be required to connect CCD cameras to the light source. Each camera will need an O-ring seal to obtain a light-tight connection to the light source. An adjustable stand will be required to change the height to the required level for the camera being tested. Finally, the system should be able to create its own plots for any number of comparisons desired by the user. For a full characterization, the program should be able to print out a formal data sheet on the camera being tested. For cameras with serious problems, this data sheet can be sent back along with the camera to the manufacturer explaining exactly what the problem is.

Figure 1:

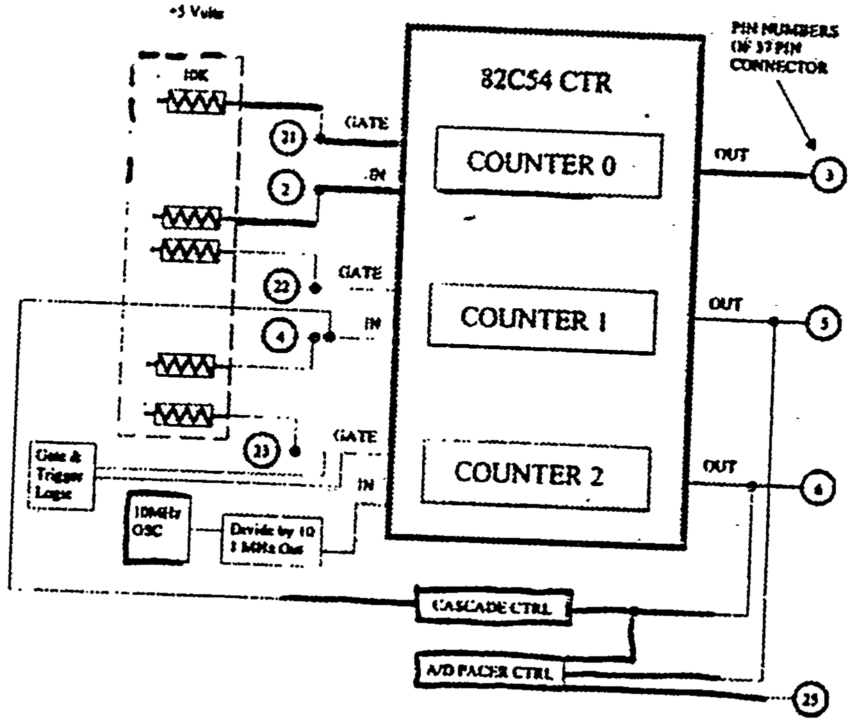


Figure 2:

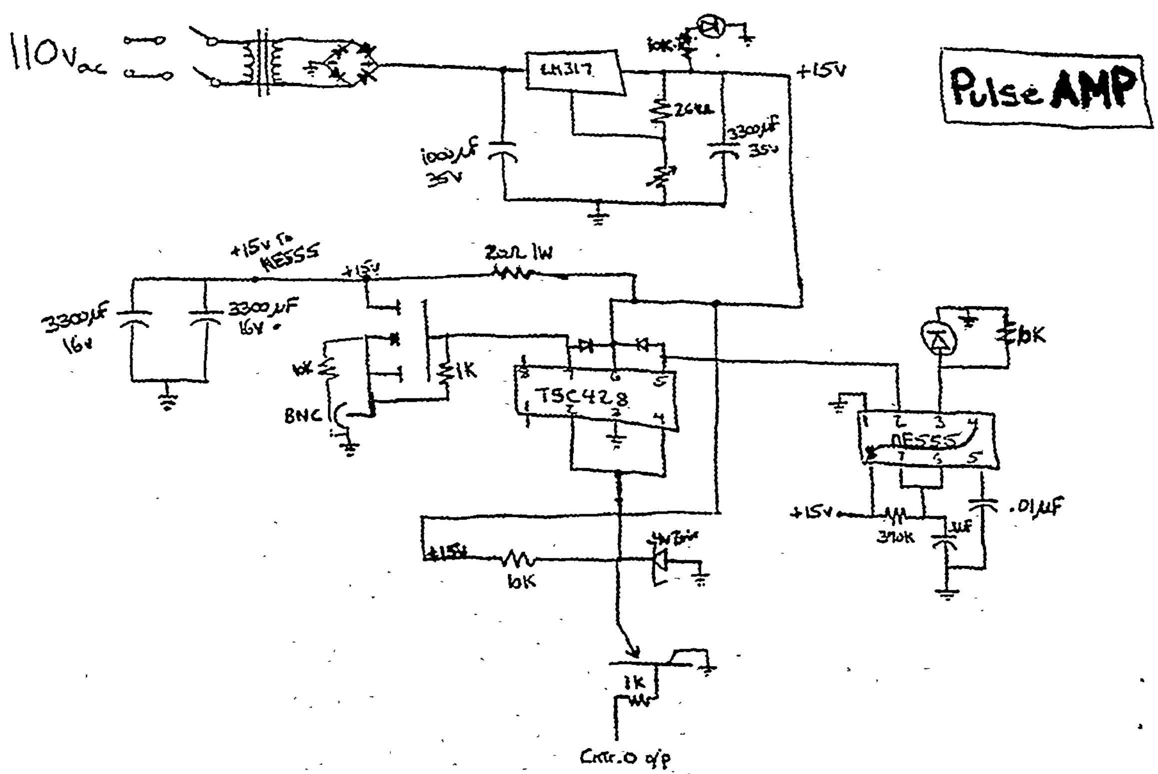
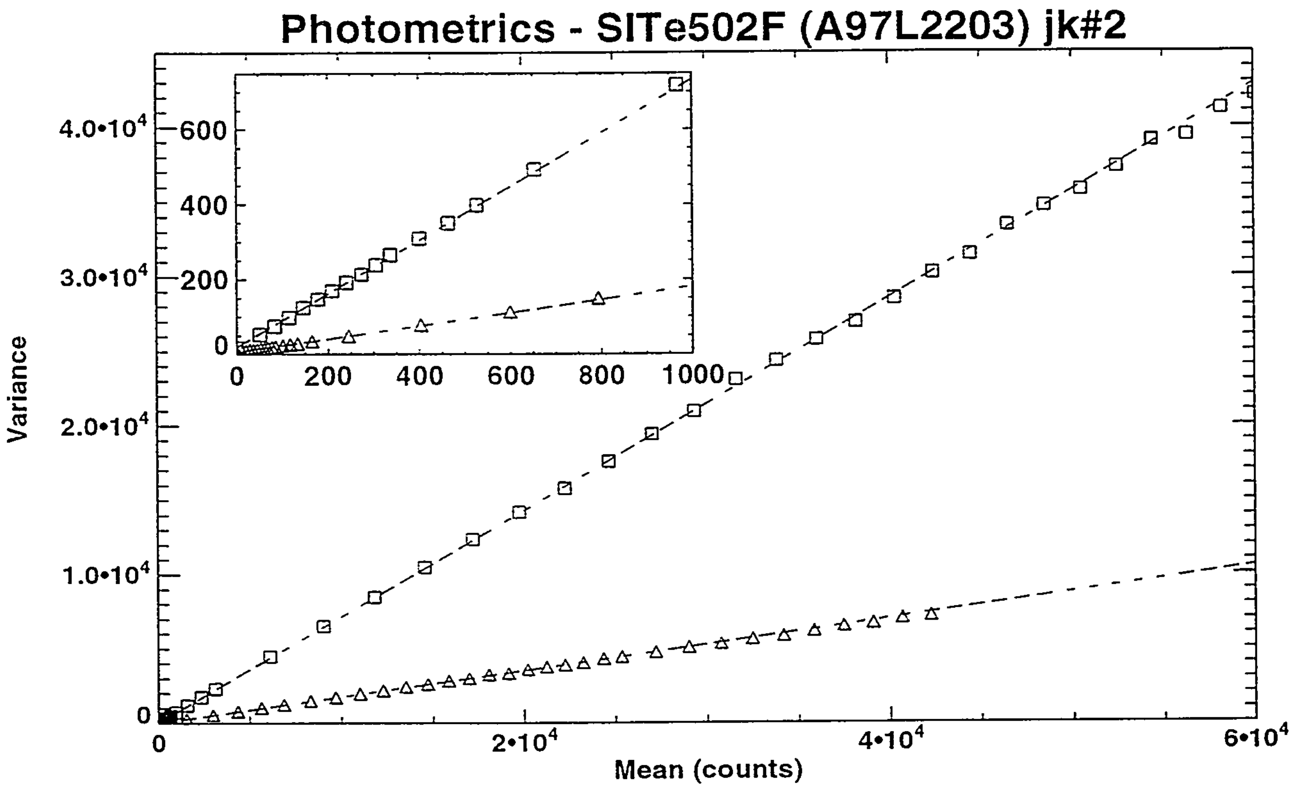
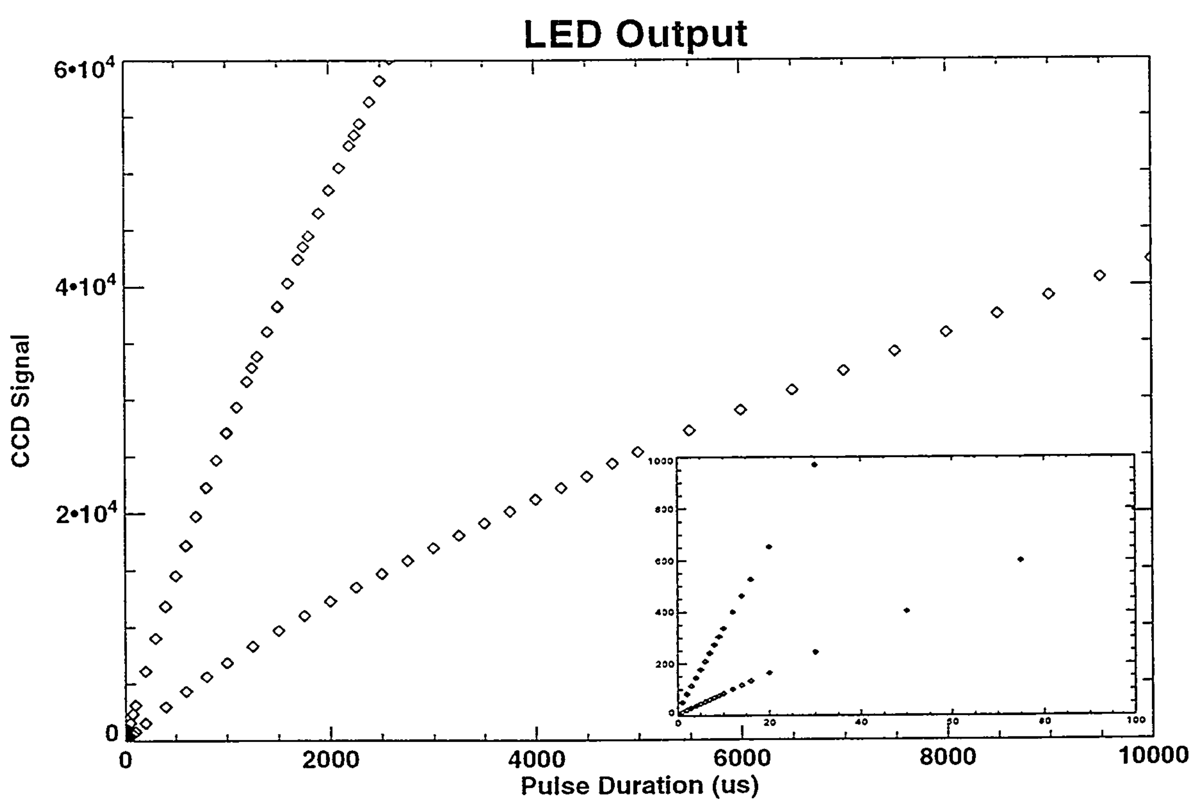


Figure 3:



LED data (8/21/98) Temp=-39 C 200kHz 16bit A/D
Gain_1 N = 46 (of 50) chi = 4 0e-01 A = 5 583378e+00 1 754221e-01 -> 5 7005 e-/cnt Noise 13 47 e-
Gain_4 N = 41 (of 45) chi = 9 0e-01 A = 1 928807e+01 7 134828e-01 -> 1 4016 e-/cnt Noise 6 16 e-

Figure 4:



Acknowledgments:

I would like to thank Dr. Robert Keck for all his help in getting my computer errors worked out with the Camtest software. Also, I would like to thank Dr. Stephen Craxton for organizing this summer's high school research program and allowing me to participate in this project. Most of all, I would like to thank my advisor Dr. Paul Jaanimagi. His help and patience this summer was much appreciated and resulted in a successful project. Dr. Jaanimagi taught me very much about everything from CCD cameras, to electronic fundamentals, to what is actually entailed in doing research. He is a fine man and I thank him very much.

References:

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